Chapter 6

Work and Kinetic Energy

PowerPoint® Lectures for
University Physics, Thirteenth Edition
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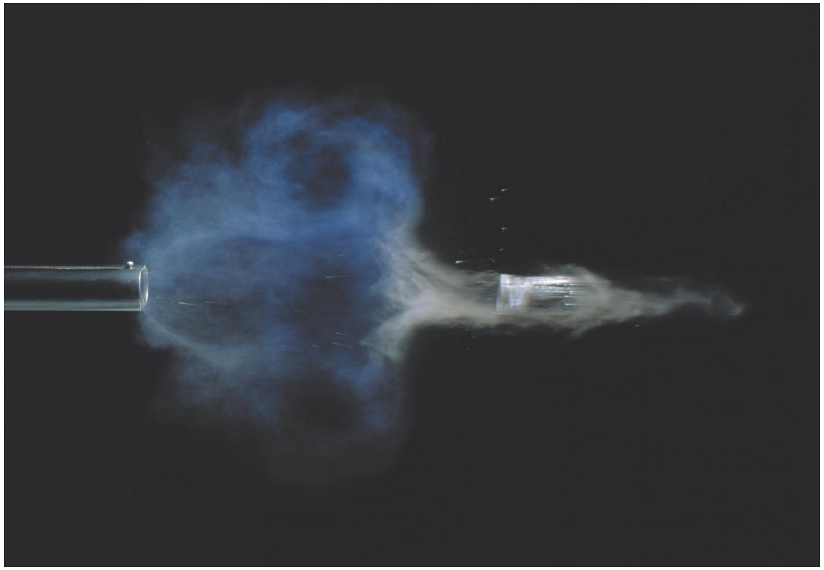
Goals for Chapter 6

- To understand and calculate work done by a force.
- To study and apply kinetic energy
- To learn and use the work-energy theorem
- To calculate work done by a varying force along a curved path
- To add time to the calculation and determine the power in a physical situation

Introduction

- We’ve studied how Newton’s Second Law allows us to calculate an acceleration from a force but what if the force changes during its application?
- We must look at action–reaction pairs that are not immediately obvious (like the shotgun expelling the pellets with expanding gas but having the expanding gas do work



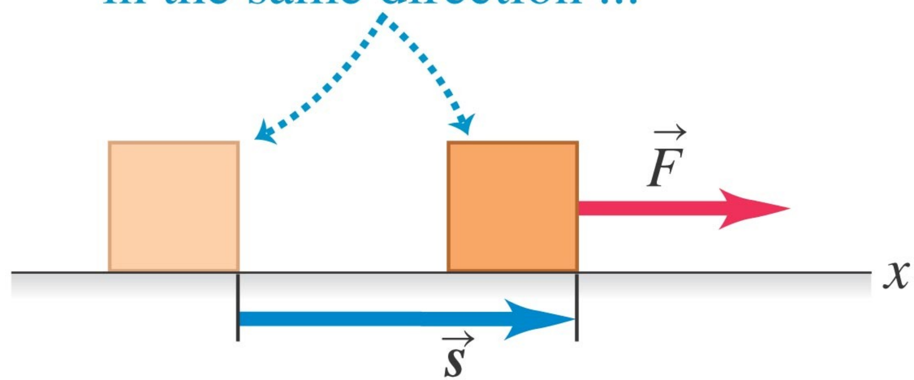
Introduction

In this chapter, though, our concentration will be on mechanics. We'll learn about one important form of energy called ***kinetic energy***, or ***energy of motion***, and how it relates to **the concept of work**. We'll also consider ***power***, ***which is the time rate of doing work***.

In Chapter 7 we'll expand the ideas of work and kinetic energy into a deeper understanding of ***the concepts of energy*** and ***the conservation of energy***.

Work, a force through a distance

- As in the illustration, pushing in the same direction that the object moves, the work done by the force is ***W=Fs.***



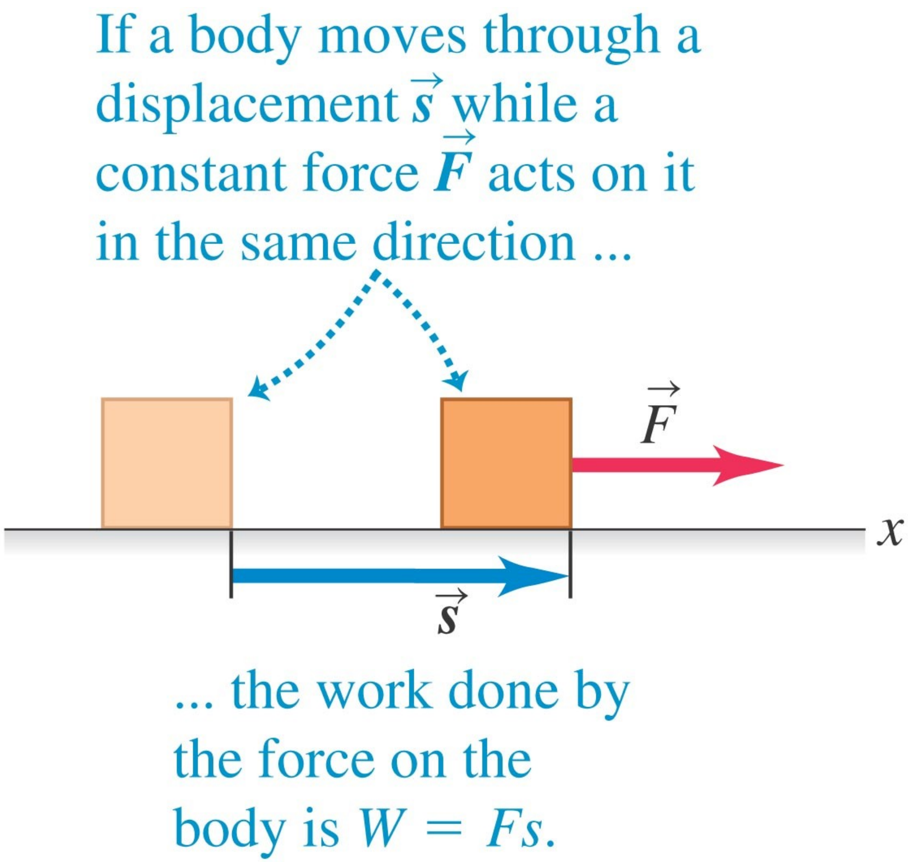
Work, a force through a distance

In physics, **work** has a much more precise definition. By making use of this definition, we'll find that in any motion, no matter how complicated, **the total work done on a particle by all forces that act on it equals the change in its kinetic energy----a quantity that's related to the particle's speed.**

This relationship holds even when *the forces* acting on the particle aren't constant. The ideas of work and kinetic energy enable us to solve problems in mechanics that we could not have attempted before.

Work, a force through a distance

Consider a body that undergoes a displacement of magnitude ***s*** along a straight line, assume the body be treated as a particle, so that we can ignore any pe of the body.



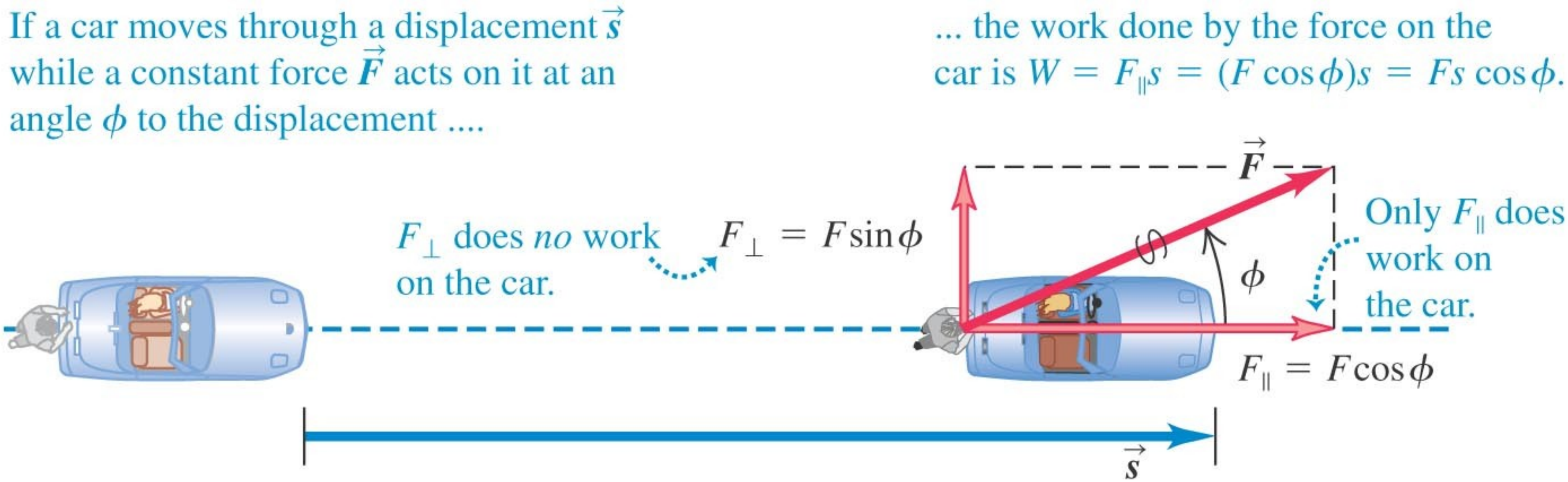
While the body moves, a constant force ***F*** acts on it in the same direction as the displacement ***s***. We define the work ***W*** done by this constant force :

$$W = Fs \tag{6.1}$$

$$1\ \mathrm{J} = 1\ \mathrm{N \cdot m}$$

$$1\ \mathrm{ft \cdot lb} = 1.356\ \mathrm{J}$$

Use the parallel component if the force acts at an angle



$$W = Fs\cos\phi \quad or \quad W = \vec{F}\cdot\vec{s}$$

Work done by constant force along straight-line.

Example 6.1 Work done by a constant force

(a) Steve exerts a steady force of magnitude *210N* on the stalled car in Fig.6.3 as he pushes it a distance of *18m*. The car also has a flat tire, so to make the car track straight Steve must push at an angle of 30° to the direction of motion. How much work does Steve do? (b) In a helpful mood, Steve pushes a second stalled car with a steady force ***F =(160i - 40j)N***. The dis[illegible]. How much work does Steve do in this case?

$$\text{(a)}\quad W = Fs\cos\phi = (210\,\text{N})(18\,\text{m})\cos 30° = 3.3 \times 10^3\,\text{J}$$

$$\text{(b)}\quad W = \vec{F}\cdot\vec{s} = F_x x + F_y y = (160\,\text{N})(14\,\text{m}) + (-40\,\text{N})(11\,\text{m})$$

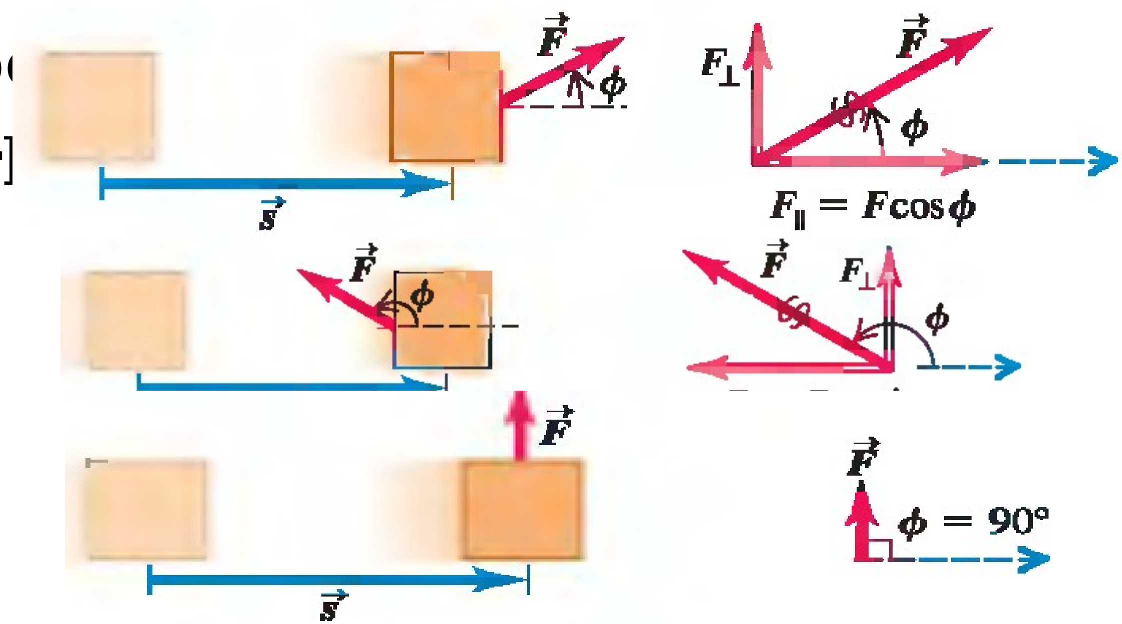
$$= 1.8 \times 10^3\,\text{J}$$

Work: Positive, Negative or Zero

It's important to understand that work can be **positive, negative or zero**. When the force has a component in the same direction as the displacement ($0<\Phi<90^0$), $\cos\Phi>0$, ***W*** is **positive** and When the force has a component opposite to the displacement ($90^0<\Phi<180^0$), $\cos\Phi<0$ and the work is **negative**. When the force is pe

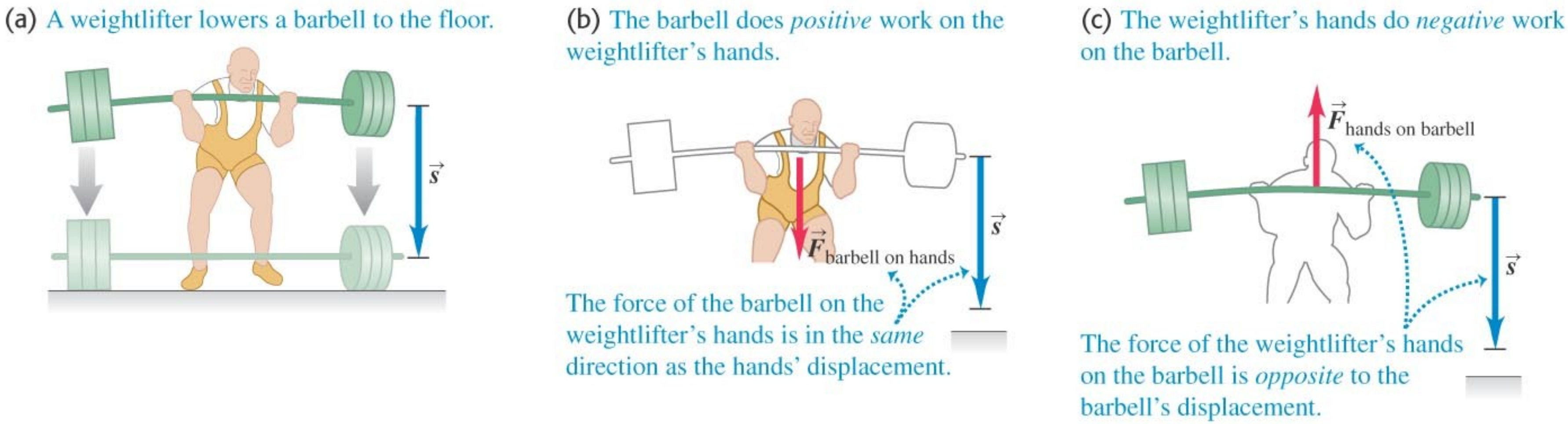
$\Phi= 90^0$ and the work

$$W = \vec{F} \cdot \vec{s}$$
$$= Fs\cos\phi$$



How can it be such a great “workout” with no work?

When positive and negative work cancel, the net work is zero even though muscles are exercising. How does the **negative** mean?

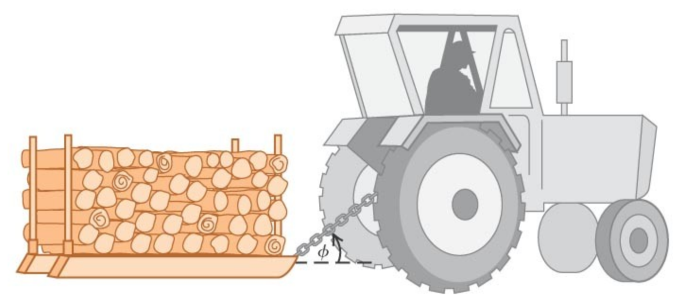


How do we calculate **work** when ***several forces*** act on a body? **One way** is to use Eq.(6.2) or (6.3) to compute the work done by each separate force. the total work W_{tot} is the **algebraic sum** of the quantities of work done by the individual forces. **An alternative way** to find the total work W_{tot} is to compute ***the vector sum of the forces*** and then

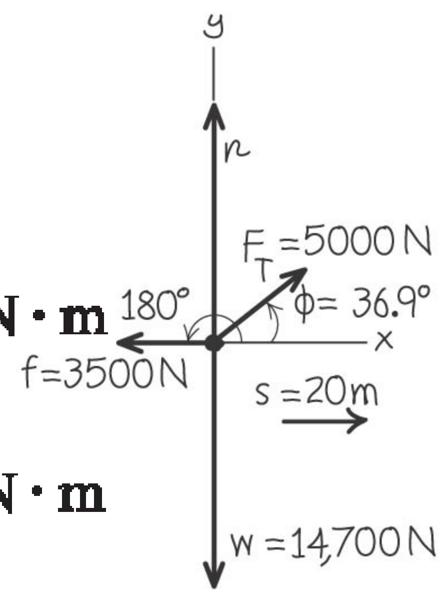
Work done by several forces

A farmer hitches her tractor to a sled loaded with firewood and pulls it a distance of 20m along level ground . The total weight of sled and load is 14700N. The tractor exerts a constant 5000N force at an angle of 36.9°above the horizontal. There is a 3500N friction force opposing the sled's motion. **Find the work done by each force** acting on the sled and the total work done by all the forces.

(a)



(b) Free-body diagram for sled

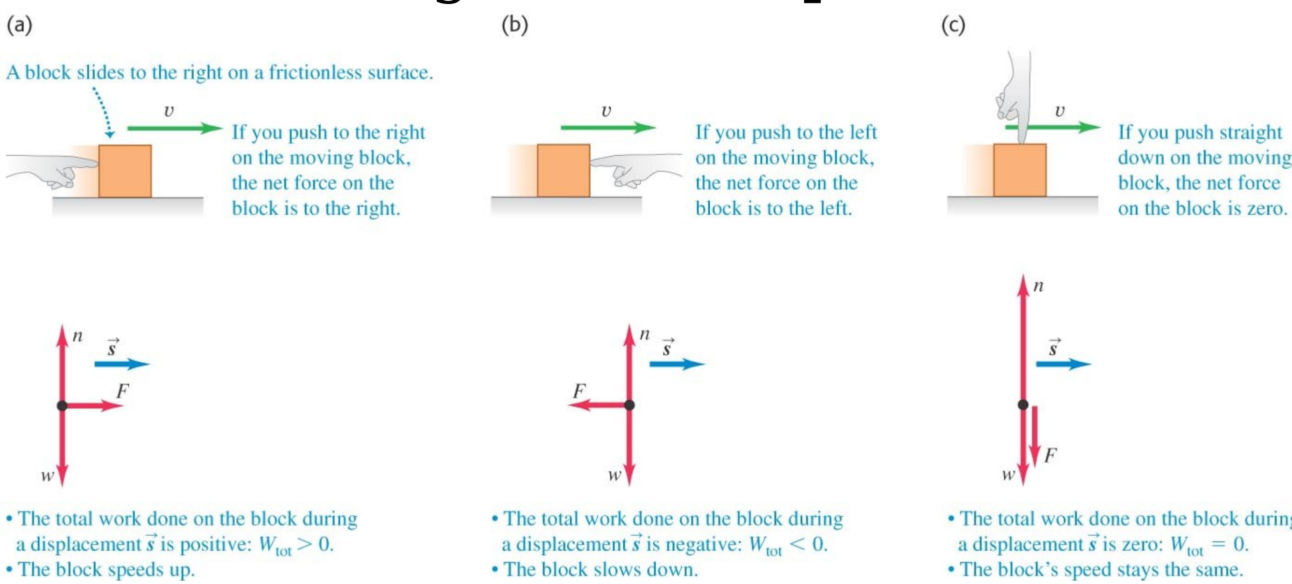


$$W_T = F_T s\cos\phi = (5000\,\mathrm{N})(20\,\mathrm{m})(0.800) = 80{,}000\,\mathrm{N\cdot m}$$
$$= 80\,\mathrm{kJ}$$

$$W_f = fs\cos 180° = (3500\,\mathrm{N})(20\,\mathrm{m})(-1) = -70{,}000\,\mathrm{N\cdot m}$$
$$= -70\,\mathrm{kJ}$$

6.2 Kinetic Energy and the Work-Energy Theorem

The total work done on a body by external forces is related to the body's displacement---that is, to changes in its position. But the total work is also related to changes in the speed of the body. *Work d*



nd energy.

We can conclude that when a particle undergoes a displacement, it speeds up if $W_{tot}>0$, slows down if $W_{tot}<0$, and maintains the same speed if $W_{tot}=0$.

The work-energy theorem

We consider a constant force.

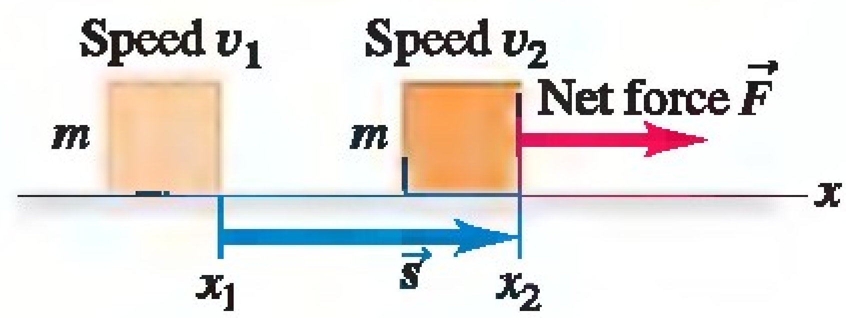
$$v_2^2 = v_1^2 + 2a_x s$$

$$a_x = \frac{v_2^2 - v_1^2}{2s}$$

$$F = ma_x = m\frac{v_2^2 - v_1^2}{2s}$$

$$Fs = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2$$

6.9 A constant net force $\vec{F}$ does work on a moving body.



The quantity ***mv²/2*** is called the ***kinetic energy K*** of the particle:

$$K = \frac{1}{2}mv^2$$

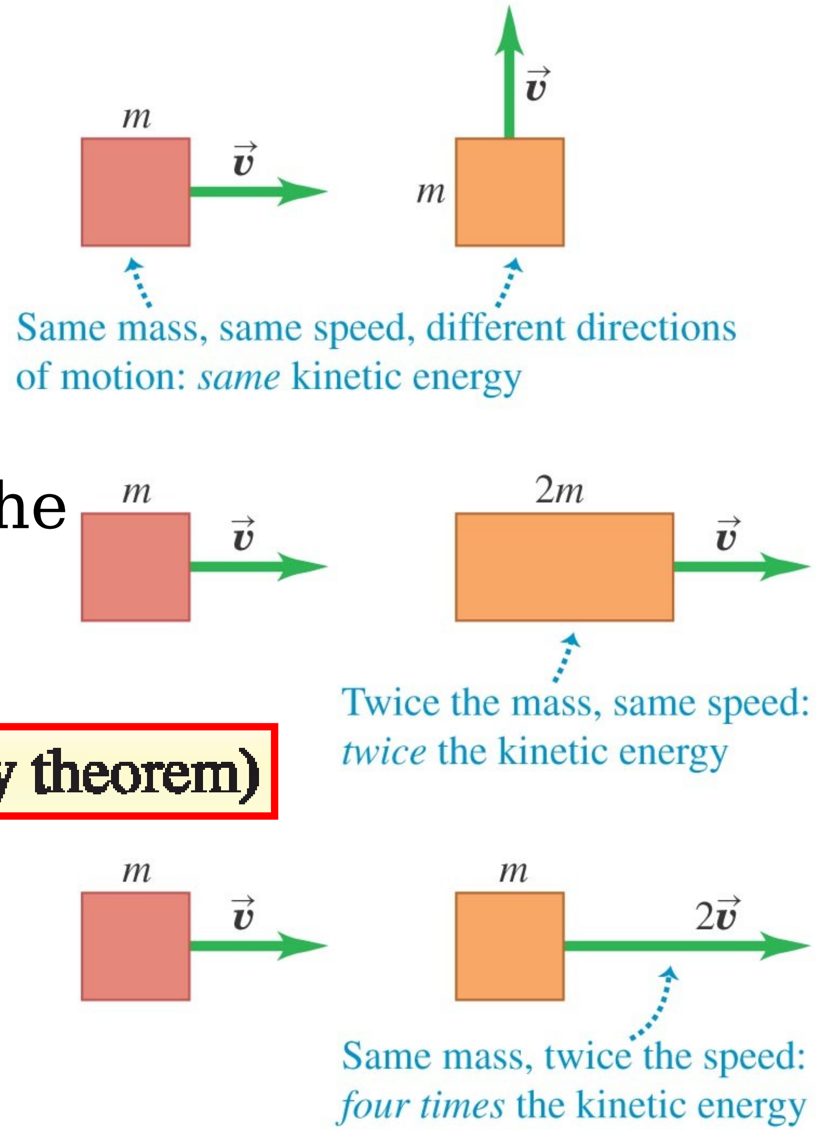
The work-energy theorem

Changes in the energy of a moving body under the influence of an applied force change differently depending on the direction of application.

The work done by the net force on a particle equals the change in the particle's kinetic energy.

$$W_{tot} = K_2 - K_1$$ (work–energy theorem)

Kinetic energy depends on only the particle's mass and speed, not its direction of motion.



The work-energy theorem

kinetic energy and work must have the same units. Hence the **joule** is the **SI** unit of both work and kinetic energy.

$K = \frac{1}{2}mv^2$ has units $\mathrm{kg \cdot (m/s)^2}$ or $\mathrm{kg \cdot m^2/s^2}$;

$1\ \mathrm{N} = 1\ \mathrm{kg \cdot m/s^2}$, so

$$1\ \mathrm{J} = 1\ \mathrm{N \cdot m} = 1\ (\mathrm{kg \cdot m/s^2}) \cdot \mathrm{m} = 1\ \mathrm{kg \cdot m^2/s^2}$$

Note : The work-energy theorem is valid in any inertial frame, but the values of W_{tot} and $K_2 - K_1$ may differ from one inertial frame to another.

We have derived the ***work-energy theorem*** for the special case of straight-line motion with constant forces, We'll find that the theorem is ***valid in general***, even when the forces are not constant and the particle's trajectory is curved

How fast?—Example 6.3

Let's look again at the sled in Fig. 6.7 and the numbers at the end of Example 6.2. Suppose the initial speed v_1 is 2.0m/s. What is the speed of the

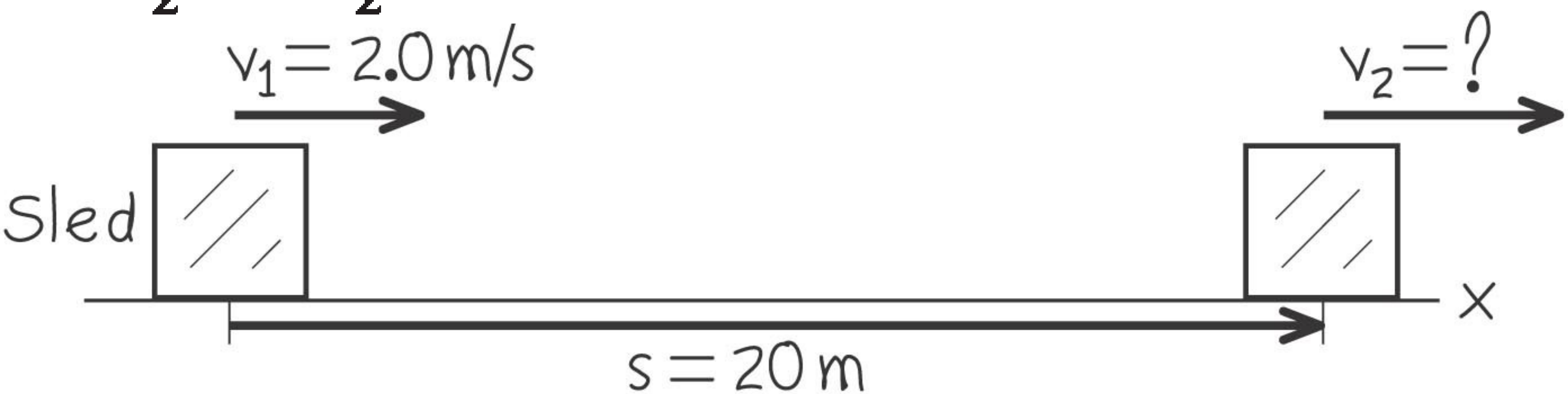
n?

$$m = \frac{w}{g} = \frac{14{,}700\ \text{N}}{9.8\ \text{m/s}^2} = 1500\ \text{kg}$$

$$K_1 = \frac{1}{2}mv_1^2 = \frac{1}{2}(1500\ \text{kg})(2.0\ \text{m/s})^2 = 3000\ \text{kg}\cdot\text{m}^2/\text{s}^2 = 3000\ \text{J}$$

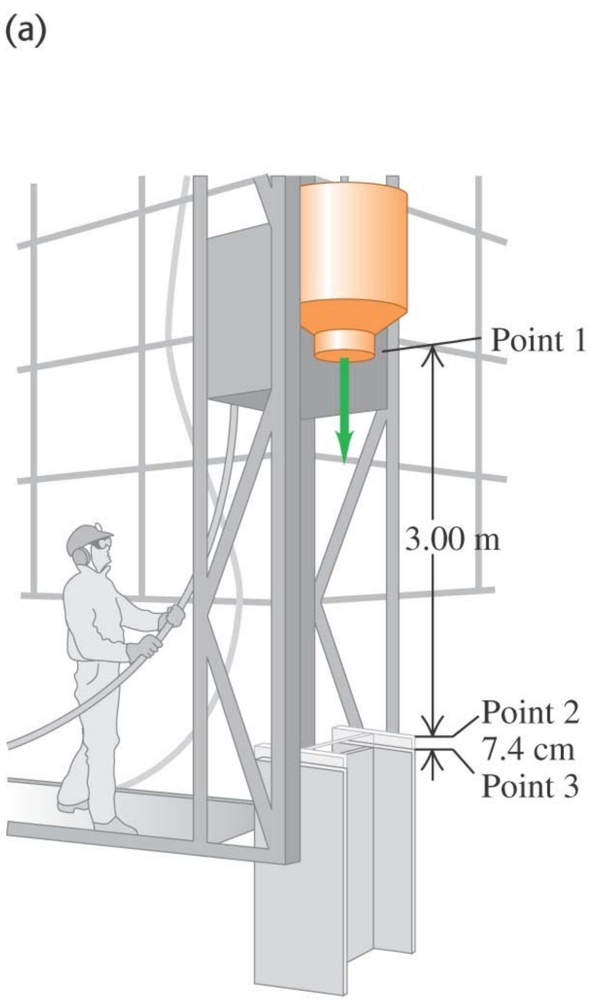
$$K_2 = K_1 + W_{tot} = 3000\ \text{J} + 10{,}000\ \text{J} = 13{,}000\ \text{J}$$

$$K_2 = \frac{1}{2}mv_2^2 = \frac{1}{2}(1500\ \text{kg})v_2^2 \qquad v_2 = 4.2\ \text{m/s}$$



Forces on a hammerhead—Example 6.4

In a pile driver, a steel hammerhead with mass *200kg* is lifted 3.00m above the top of a vertical I-beam being driven into the ground. The hammer is then dropped. driving the I-beam *7.4*cm farther into the ground. The vertical rails that guide the hammerhead exert a constant *60N* friction force on the hammerhead. Use the work-energy theorem to find (a) the speed of the hammerhead just as it hits the I-beam and (b) the average force



Forces on a hammerhead—Example 6.4

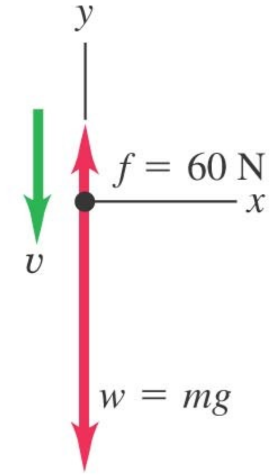
Identify and set up: Use the work--energy theorem to relate the hammerhead's speed at different locations and the forces acting on it. Free-body diagram to solve the motion of a pile driver.

Execute: From point 1 to point 2, the vertical forces are the downward weight

$$w = mg = (200\,\text{kg})(9.8\,\text{m/s}^2) = 1960\,\text{N}$$

The upward friction force ***f=60N***

Thus the net downward force is ***w-f =1900N.***



(b) Free-body diagram for falling hammerhead

The displacement ***S_{12}=3.00m***. The total work done on the hammerhead as it moves from point 1 to point 2 is then

$$W_{tot} = (w - f)s_{12} = (1900\,\text{N})(3.00\,\text{m}) = 5700\,\text{J}$$

$$W_{tot} = K_2 - K_1 = K_2 - 0 = \frac{1}{2}mv_2^2 - 0$$

$$v_2 = \sqrt{\frac{2W_{tot}}{m}} = \sqrt{\frac{2(5700\,\text{J})}{200\,\text{kg}}} = 7.55\,\text{m/s}$$

Forces on a hammerhead—Example 6.4

(b) As the hammerhead moves downward between points 2 and 3, the net downward force acting on it is ***w-f-n.***

The total work done on the hammerhead during this displacement is

$$W_{\text{tot}} = (w - f - n)s_{23}$$

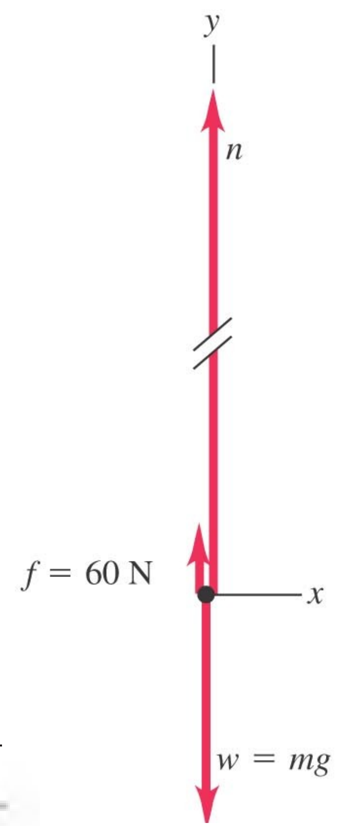
The initial kinetic energy for this part of the motion is ***K_2***, which from part (a) equals ***5700J***. The final kinetic energy is ***K_3= 0***, since the hammerhead ends at rest. Then, from the work-energy theorem,

$$W_{\text{tot}} = (w - f - n)s_{23} = K_3 - K_2$$

$$n = w - f - \frac{K_3 - K_2}{s_{23}} = 1960\ \text{N} - 60\ \text{N} - \frac{0\ \text{J} - 5700\ \text{J}}{0.074\ \text{m}}$$

$$= 79{,}000\ \text{N}$$

(c) Free-body diagram for hammerhead pushing I-beam



The meaning of kinetic energy

The kinetic energy of a particle is equal to the total work that was done to accelerate it from rest to its present speed.

The kinetic energy of a particle is equal to the total work that particle can do in the process of being brought to rest.

This is why you pull your hand and arm backward when you catch a ball. As the ball comes to rest, it does an amount of work (force times distance) on your hand equal to the ball's initial kinetic energy. By pulling your hand back, you maximize the distance over which the force acts and so minimize the force on your hand.

Different objects, different kinetic energies

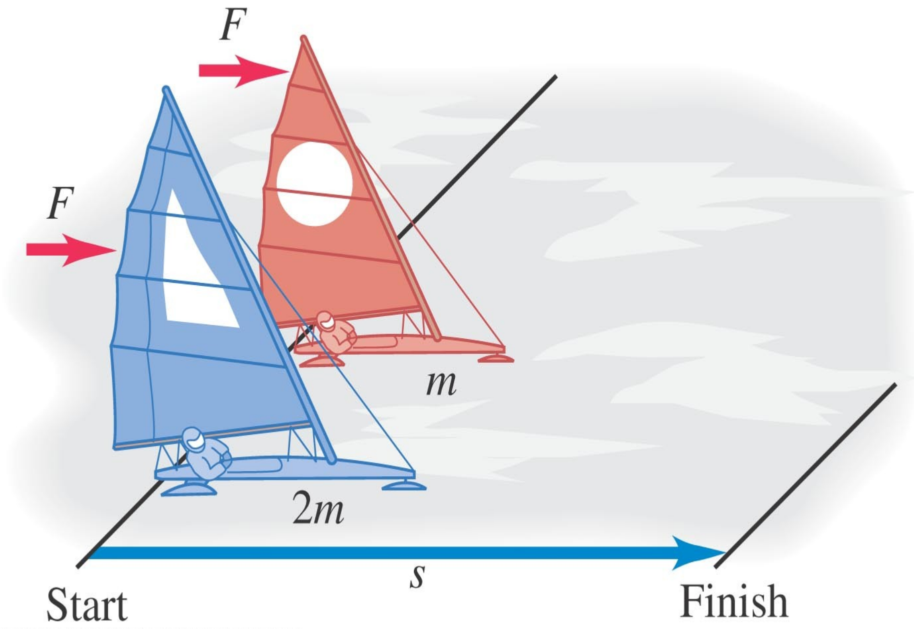
Two iceboats hold a race on a frictionless horizontal lake. The two iceboats have masses ***m*** and ***2m***. Each iceboat has an identical sail, so the wind exerts the same constant force ***F*** on each iceboat. The two iceboats start from rest and cross the finish line a distance ***s*** away. *Which iceboat crosses the finish line with greater kinetic energy*?

The kinetic energy of a particle is equal to the total work done to ac e it from rest.

$$W_{tot} = Fs$$

$$W_{tot} = K - 0 = K$$

So both iceboats have the same kinetic energy at the finish line!



6.3 Work and Energy with Varying Forces

We've considered work done by constant forces only. But what happens when you stretch a spring? The more you stretch it, the harder you have to pull, so the force you exert is **not constant** as the spring is stretched.

There are many situations in which a body moves along **a curved path** and is acted on by **a force that varies** in magnitude, direction, or both. We need to be able to compute the work done by the force in these more general cases.

Fortunately, we'll find that **the work-energy theorem** holds true even when varying forces are considered and when the body's path is not straight.

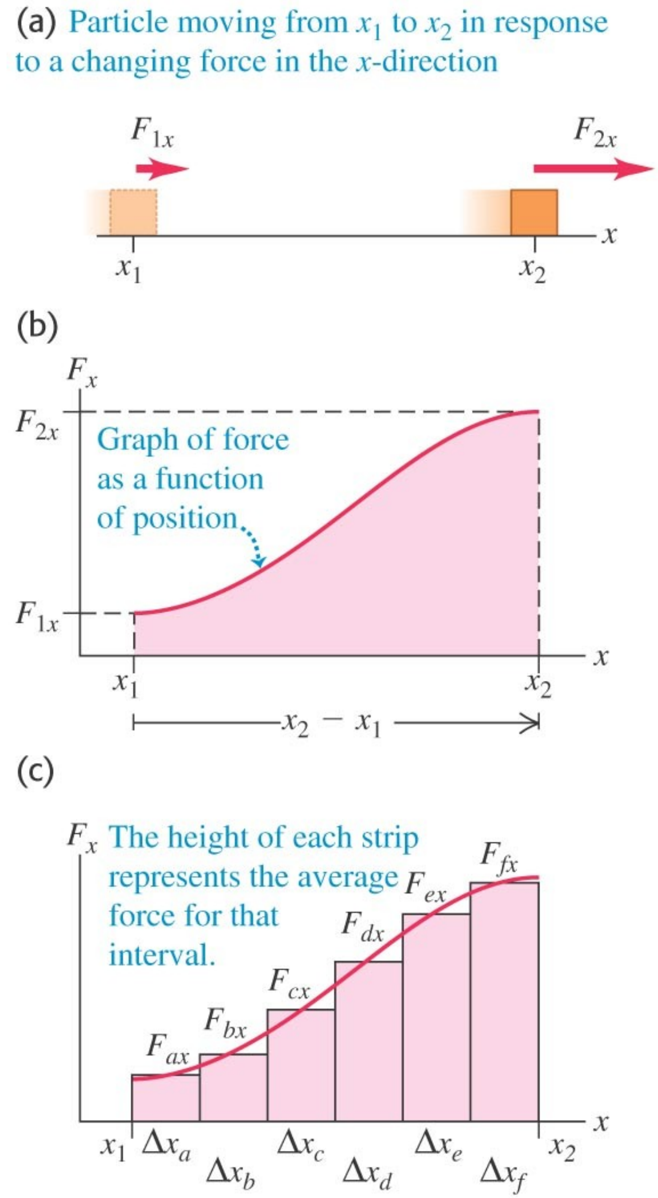
Work Done by a Varying Force, Straight-Line Motion

Perhaps the best example is driving a car, alternating your attention between the gas and the brake.

The effect is a variable positive or negative force of various ma $W = F_{ax}\Delta x_a + F_{bx}\Delta x_b + \cdots$ line.

In the limit that the number of segments becomes very large and the width of each becomes very small, this sum becomes the integral of F_x from x_1 to x_2:

$$W = \int_{x_1}^{x_2} F_x \, dx \qquad (6.7)$$



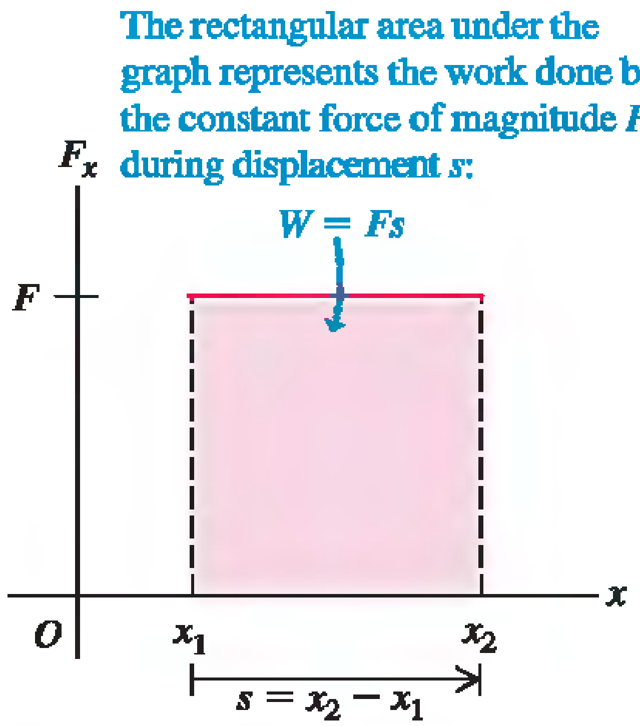
Work Done by a Varying Force, Straight-Line Motion

On a graph of force as a function of position, the total work done by the force is represented by the area under the curve between the initial and final positions.

In the special case that F_x the *x-component* of the force, is constant, it may be taken outside the integral in Eq. (6.7):

$$W = \int_{x_1}^{x_2} F_x\,dx = F_x \int_{x_1}^{x_2} dx = F_x(x_2 - x_1)$$

6.17 The work done by a constant force F in the x-direction as a particle moves from x_1 to x_2.



$F_x = kx$ The stretch of a spring and the force that caused it

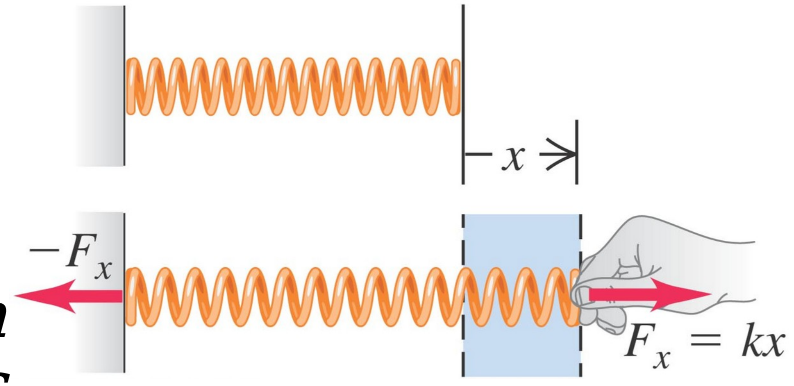
The force applied to an ideal spring will be proportional to its stretch.

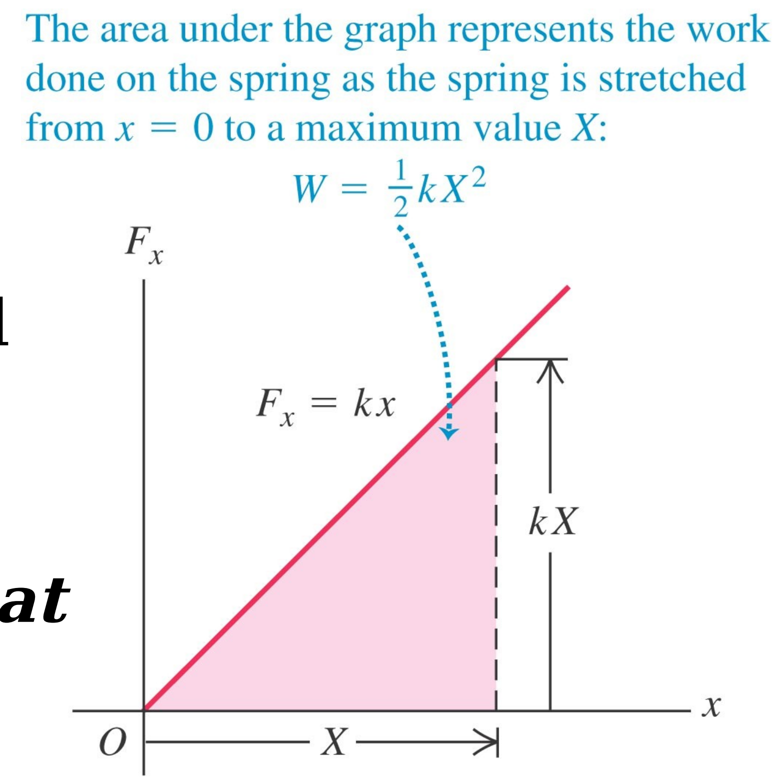
$$F_x = kx \quad 6.8$$

The graph of force on versus stretch on the x axis will yield a slope of k, the spring constant.

$$W = \int_0^x F_x dx' = \int_0^x kx' dx' = \frac{1}{2}kx^2 \quad 6.9$$

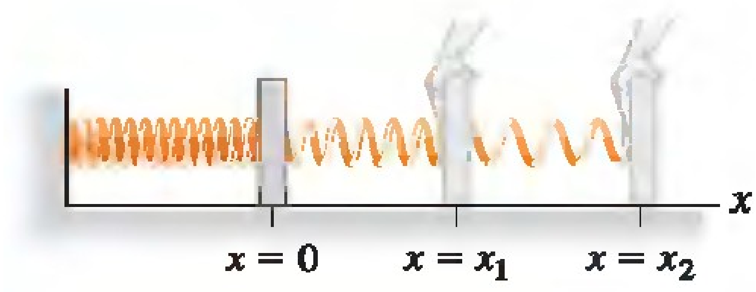
The units of ***k*** are force divided by distance: ***N/m*** in SI units. The observation that force is directly proportional to elongation ***for elongations that are not too great*** is known as **Hooke's law**.





The stretch of a spring and the force that caused it

Equation (6.9) assumes that the spring was originally unstretched. If initially the spring is already stretched a distance $\boldsymbol{x_1}$ the work we must do to stretch it to a greater elongation $\mathbf{x_2}$ is



$$W = \int_{x_1}^{x_2} F_x dx' = \int_{x_1}^{x_2} kx' dx' = \frac{1}{2}kx_2^2 - \frac{1}{2}kx_1^2 \quad 6.10$$

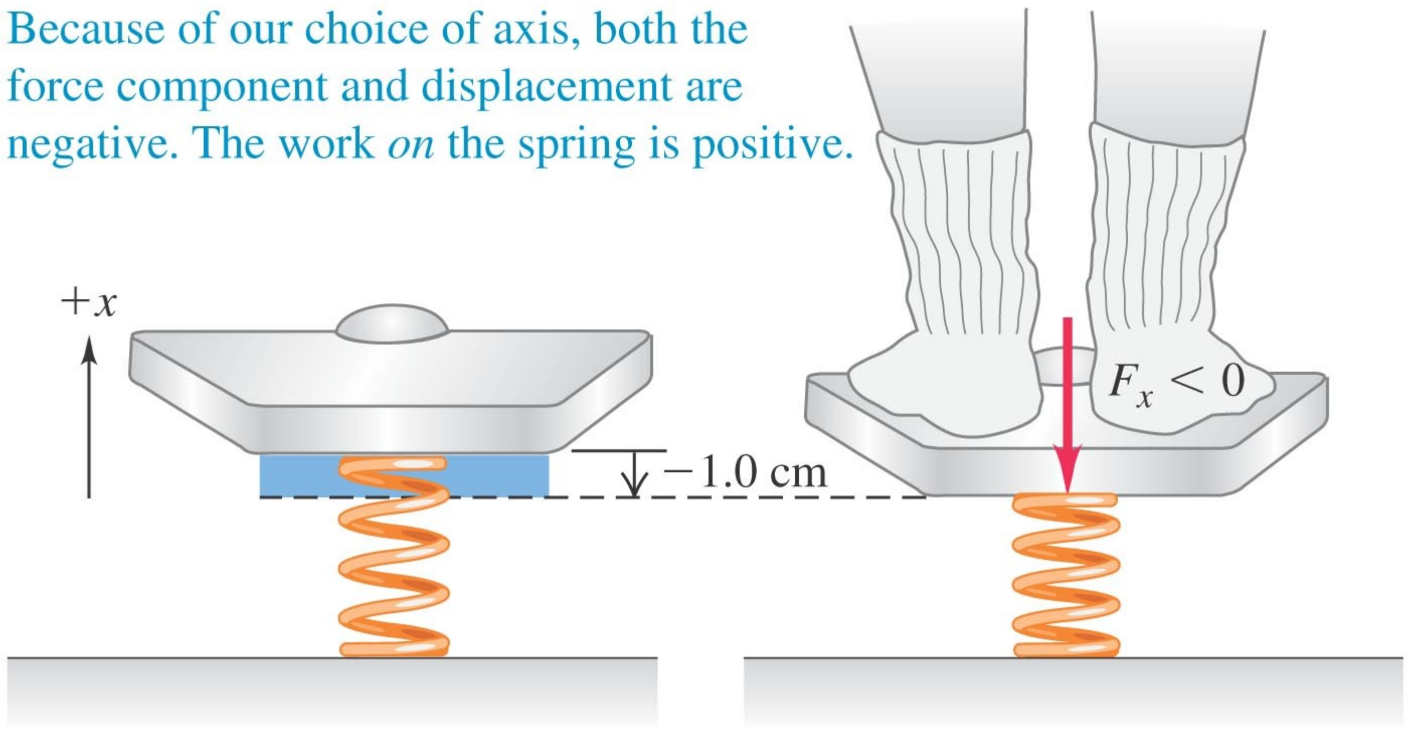
tion:

rk done on a spring vs. work done by a spring

Eq.(6.10) gives the work that you must do on a spring to change its length. Thus, as you pull on the spring, the spring does negative work on you.

Example 6.6 Work done on a spring

A woman weighing *600N* steps on a bathroom scale containing a stiff spring. In equilibrium the spring is compressed *1.0cm* under her weight. Find the force constant of the spring and the total work done on it during the compression.



Example 6.6 Work done on a spring

Identify: In equilibrium the upward force exerted by the spring balances the downward force of the woman's weight. We'll use this principle and Eq.(6.8) to determine the force constant ***k***, and use Eq.(6.10) to calculate the work ***W*** that the woman does on the spring to compress.

Set up: We take positive values of *x* to correspond to elongation (upward), so that the displacement of the spring (*x*) and the x-component of the force that the woman exerts on it (*F*) are both negative.

Execute: The top of the spring is displaced by $x=-1.0cm=-0.01m$. The woman exerts $F_x=-600N$ on th

$$k = \frac{F_x}{x} = \frac{-600\ \text{N}}{-0.010\ \text{m}} = 6.0 \times 10^4\ \text{N/m}$$

$$W = \frac{1}{2}kx_2^2 - \frac{1}{2}kx_1^2 = \frac{1}{2}(6.0 \times 10^4\ \text{N/m})(-0.010\ \text{m})^2 - 0 = 3.0\ \text{J}$$

Work-Energy Theorem for varying Forces

Here's a derivation of the work-energy theorem for a force that *may vary with position*. It involves making a change of variable from x to v_x **in the work in**

$$a_x = \frac{dv_x}{dt} = \frac{dv_x}{dx}\frac{dx}{dt} = v_x\frac{dv_x}{dx} \qquad (6.11)$$

$$W_{\text{tot}} = \int_{x_1}^{x_2} F_x\,dx = \int_{x_1}^{x_2} ma_x\,dx = \int_{x_1}^{x_2} mv_x\frac{dv_x}{dx}\,dx \qquad (6.12)$$

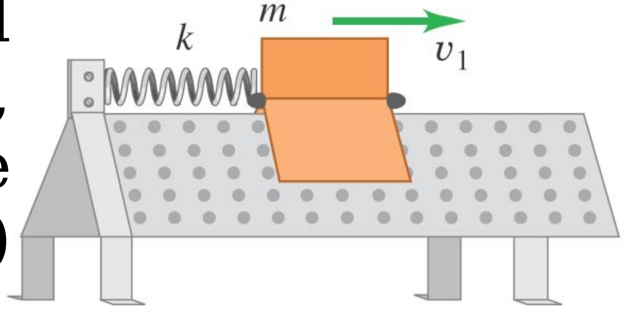
$$W_{\text{tot}} = \int_{v_1}^{v_2} mv_x\,dv_x$$

$$W_{\text{tot}} = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2 \qquad (6.13)$$

Motion with a varying force—Example 6.7

An air-track glider of mass *0.100 kg* is attached to the end of a horizontal air track by a spring with force constant *20.0N/m*. Initially the spring is unstretched and the glider is moving at *1.50m/s* to the right. Find the maximum distance *d* that the glider moves to the right (a) if the air track is turned on so that there is no friction, and (b) if the air is turned off so that there is kinetic friction with coefficient $\mu_k = 0.47$.

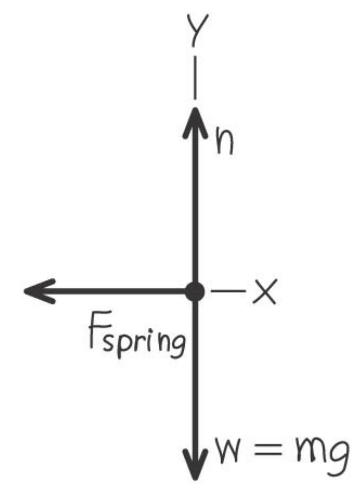
Identify: The force exerted by the spring is not constant, we'll use the work--energy theorem, which involves the distance moved (our target variable) through the formula for work.



Motion with a varying force—Example 6.7

Set up: In Figure b and c, we chose the positive *x-direction* to be to the right, take *x=0* at the glider's initial position (where the spring is unstretched) and *x=d* (target variable) at the position where the glider stops. The motion is purely horizontal, so only the horizo[illegible]ork.

(b) Free-body diagram for the glider without friction

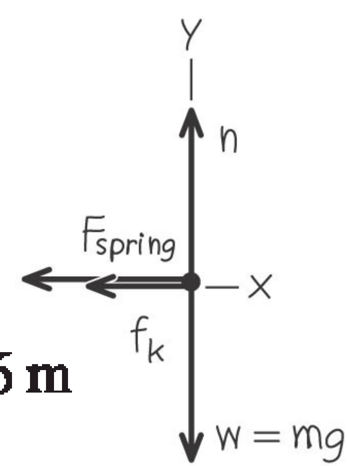


Execute:

$$-\frac{1}{2}kd^2 = 0 - \frac{1}{2}mv_1^{2}$$

$$d = v_1\sqrt{\frac{m}{k}} = (1.50\ \mathrm{m/s})\sqrt{\frac{0.100\ \mathrm{kg}}{20.0\ \mathrm{N/m}}} = 0.106\ \mathrm{m} = 10.6\ \mathrm{cm}$$

(c) Free-body diagram for the glider with kinetic friction



$$W_{\mathrm{fric}} = f_k d\cos 180^\circ = -f_k d = -\mu_k mgd$$

$$-\mu_k mgd - \frac{1}{2}kd^2 = 0 - \frac{1}{2}mv_1^{2}$$

$$d = \frac{-(0.461\ \mathrm{N}) \pm \sqrt{(0.461\ \mathrm{N})^2 - 4(10.0\ \mathrm{N/m})(-0.113\ \mathrm{N\cdot m})}}{2(10.0\ \mathrm{N/m})} = 0.086\ \mathrm{m}$$

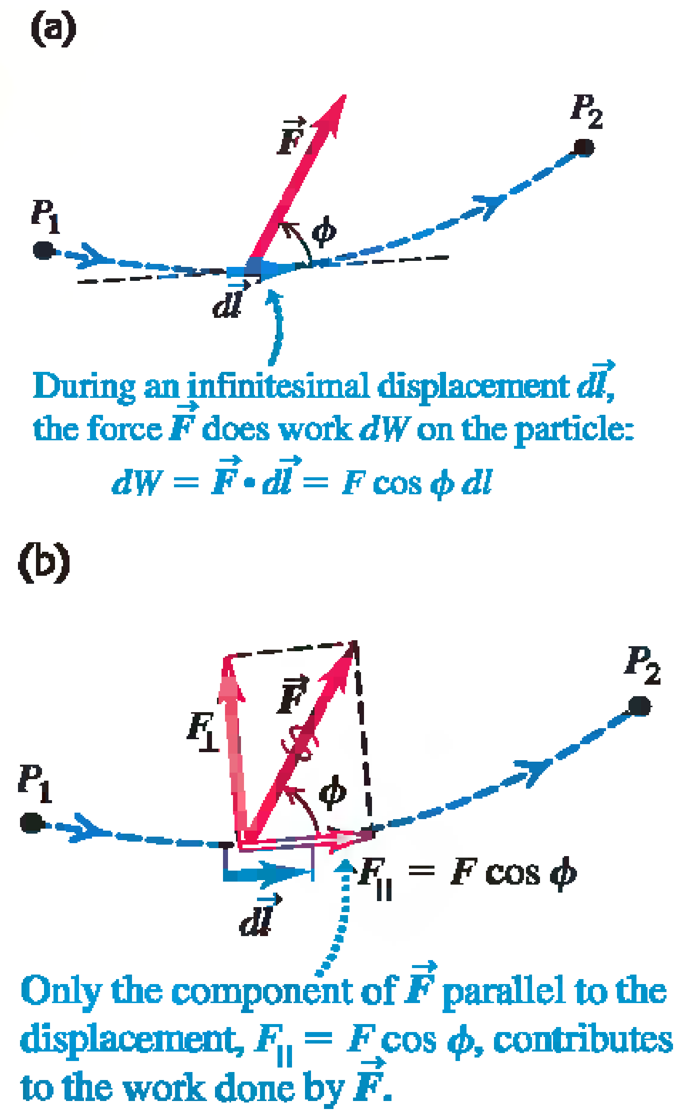
Work-Energy Theorem for Motion Along a Curve

Suppose a particle moves from point P_1 to P_2 along a curve. We divide the portion of the curve between these points into many *infinitesimal vector* c... all a typical one of these $d\vec{l}$

$$dW = F\cos\phi\, dl = F_{\parallel}\, dl = \vec{F}\cdot d\vec{l}$$

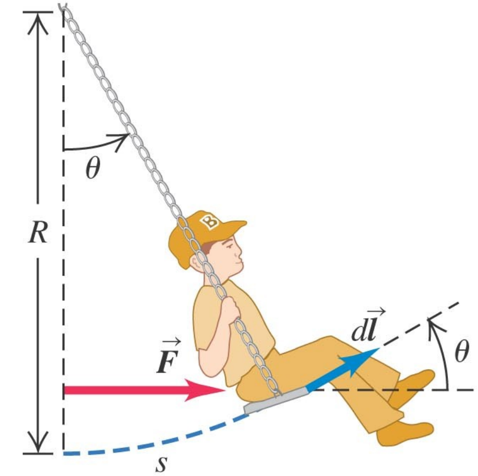
$$W = \int_{P_1}^{P_2} F\cos\phi\, dl = \int_{P_1}^{P_2} F_{\parallel}\, dl = \int_{P_1}^{P_2} \vec{F}\cdot d\vec{l}$$

Note that only the component of the net force parallel to the path, does work on the particle, so can change the speed and kinetic energy of the particle. The component perpendicular to the path, has no effect on the particle's speed; it acts only to



Work-Energy Theorem for Motion Along a Curve

If you watch a child on a swing set, you can also consider the motion of a particle along a curved path. *(example 6.8)*



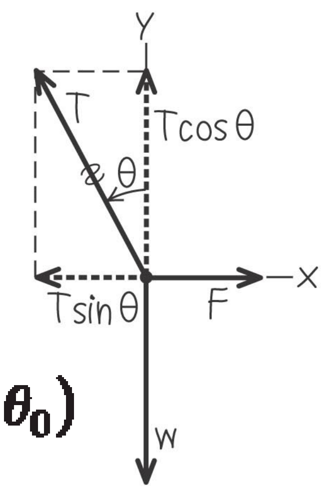
What is the total work done on the boy by all forces? What is the work done by the tension $\boldsymbol{T}$ in the chains? What is ***the work*** you do by exerting the force $\boldsymbol{F}$?

$$\sum F_x = F + (-T\sin\theta) = 0$$

$$\sum F_y = T\cos\theta + (-w) = 0$$

$$F = w\tan\theta$$

(b) Free-body diagram for Throckmorton (neglecting the weight of the chains and seat)



The point where $\boldsymbol{F}$ is applied swings through the arc s. in circular mot

$$s = R\theta$$

$$dl = ds = R\,d\theta.$$

$$W = \int \vec{F}\cdot d\vec{l} = \int F\cos\theta\, ds$$

$$W = \int_0^{\theta_0} (w\tan\theta)\cos\theta\,(R\,d\theta) = wR\int_0^{\theta_0}\sin\theta\,d\theta = wR(1-\cos\theta_0)$$

Work-Energy Theorem for Motion Along a Curve

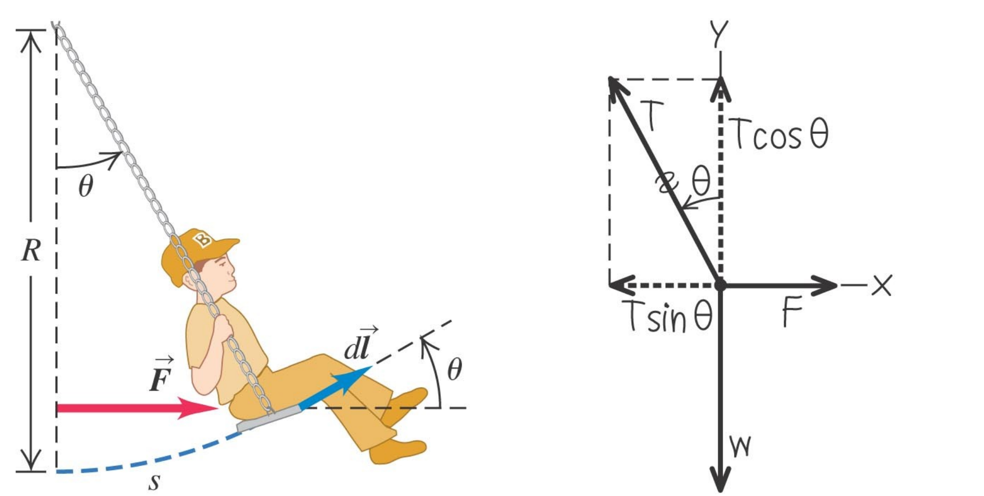
In Example 6.8 the infinitesimal displacement ***dl*** has a magnitude of ***dl***, an *x-component* of *dlcosθ*, and a y-component of *dlsinθ*. Hence *d**l**=**i**dlcosθ +**j**dlsinθ*. Use this expression and Eq.(6.14) to calculate the work done during the motion by the chain tension, by the force of gravity, and by the force F.

Identify: We use Eq. (6.14), but now we'll use Eq.(1.21) to find the scalar product in terms of components.

Set up: We use the same free-body diagram, Fig. 6.24b, as in Example 6.8.

(a)

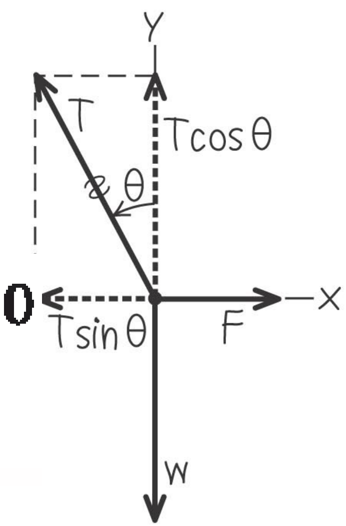
(b) Free-body diagram for Throckmorton (neglecting the weight of the chains and seat)



Execute: From Fig.6.24b, we can write the three forces in terms of unit vectors:

$$\vec{T} = \hat{\imath}(-T\sin\theta) + \hat{\jmath}T\cos\theta \qquad \vec{w} = \hat{\jmath}(-w) \qquad \vec{F} = \hat{\imath}F$$

(b) Free-body diagram for Throckmorton (neglecting the weight of the chains and seat)



To use Eq.(6.14), we must calculate the scalar product of each of these forces with *dl*. Using Eq.(1.21),

$$\vec{T}\cdot d\vec{l} = (-T\sin\theta)(ds\cos\theta) + (T\cos\theta)(ds\sin\theta) = 0$$

$$\vec{w}\cdot d\vec{l} = (-w)(ds\sin\theta) = -w\sin\theta\, ds$$

$$\vec{F}\cdot d\vec{l} = F(ds\cos\theta) = F\cos\theta\, ds$$

Since $\vec{T}\cdot d\vec{l} = 0$ The work done by the chain tension is zero.

Gravity $\int \vec{w}\cdot d\vec{l} = \int (-w\sin\theta)\,R\,d\theta = -wR\int_0^{\theta_0} \sin\theta\, d\theta = -wR(1-\cos\theta_0)$

Force ***F***: $W = \int_0^{\theta_0} (w\tan\theta)\cos\theta\,(R\,d\theta) = wR\int_0^{\theta_0} \sin\theta\, d\theta = wR(1-\cos\theta_0)$

6.4 Power

In physics we use a much more precise definition: **Power** is the time rate at which work is done. Like work and energy, power is a scalar quantity.

When a quantity of work ΔW is done during a time interval Δt, the average work done per unit time or average power P_{av} is defined to be

$$P_{av} = \frac{\Delta W}{\Delta t} \qquad \text{(average power)} \qquad (6.15)$$

We can define ***instantaneous power P*** as the quotient in Eq. (6.15) as Δt approaches zero:

$$P = \lim_{\Delta t \to 0} \frac{\Delta W}{\Delta t} = \frac{dW}{dt} \qquad \text{(instantaneous power)} \qquad (6.16)$$

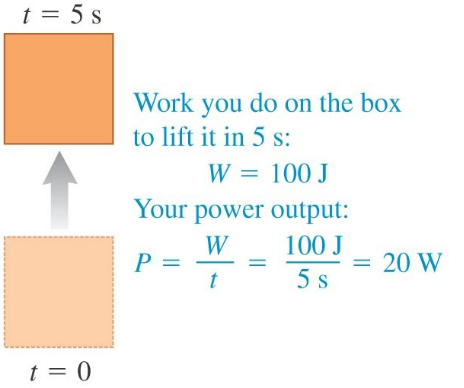
The SI unit of power is the watt (***W***), named for the English inventor **James Watt**. One watt equals 1 joule per second: ***1W = 1J/s***.

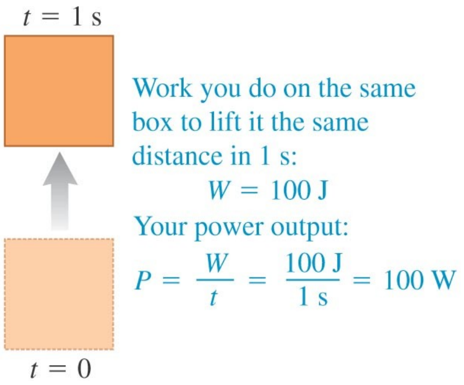
Power

The kilowatt (1kW=10^3W) and the megawatt (1MW=10^6W) are also commonly used.

$$1\ \text{hp} = 746\ \text{W} = 0.746\ \text{kW}$$

The watt is a familiar unit of electrical power; a *100W* light bulb converts *100J* of electrical energy into light and heat ***each second***. But there's nothing inherently electrical about a watt.





Power

A light bulb could be rated in horsepower, and an engine can be rated in kilowatts.

The energy you use may be noted from the meter the electric company probably installed to measure your consumption of energy in ***kilowatt-hours* (*kWh*)**

$$1\ \mathrm{kW \cdot h} = (10^3\ \mathrm{J/s})(3600\ \mathrm{s}) = 3.6 \times 10^6\ \mathrm{J} = 3.6\ \mathrm{MJ}$$

kilowatt-hour is a unit of *work or energy*, not *power*.

In mechanics we can also express power in terms of force and velocity. The average power is

$$P_{av} = \frac{F_{\parallel}\Delta s}{\Delta t} = F_{\parallel}\frac{\Delta s}{\Delta t} = F_{\parallel}v_{av} \qquad (6.17)$$

ntaneous power ***P*** is the limit of this expression as $\Delta t \to 0$

$$P = F_{\parallel}v \qquad (6.18)$$

$$P = \vec{F} \cdot \vec{v} \quad \text{(instantaneous rate at which force } \vec{F} \text{ does work on a particle)} \qquad (6.19)$$

Force and power you depend upon—Example 6.10

Each of the two jet engines in a Boeing 767 airliner develops a thrust (a forward force on the airplane) of ***197,000N***. When the airplane is flying at ***250m/s***, what horsepower does each engine develop?

Identify: Our target variable is the instantaneous power ***P***,

$$P = F_{\parallel}v = (1.97 \times 10^5\ \text{N})(250\ \text{m/s})$$

$$= 4.93 \times 10^7\ \text{W}$$

$$= (4.93 \times 10^7\ \text{W})\frac{1\ \text{hp}}{746\ \text{W}}$$

$$= 66{,}000\ \text{hp}$$

(a)

(a) Propeller-driven and (b) jet airliner

(b)

An example you might do if the elevator is out

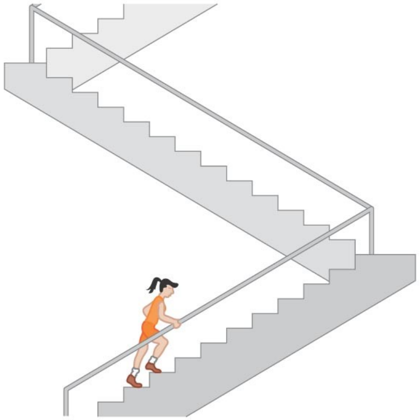
A **50.0kg** marathon runner runs up the stairs to the top of Chicago's *443m-tall* Sears Tower, the tallest building in the United States. To lift herself to the top in *15.0 minutes*, what must be her average power output in watts? In kilowatts? In horsepower?

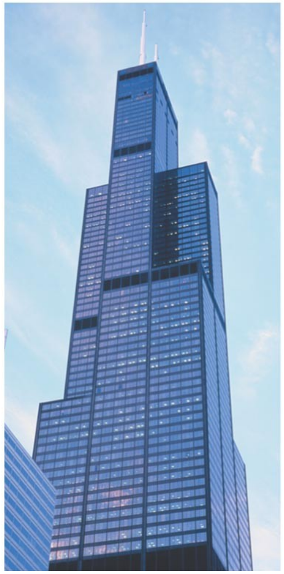
$$W = mgh = (50.0\ \text{kg})(9.80\ \text{m/s}^2)(443\ \text{m})$$

$$= 2.17 \times 10^5\ \text{J}$$

$$P_{av} = \frac{2.17 \times 10^5\ \text{J}}{900\ \text{s}} = 241\ \text{W}$$

$$= 0.241\ \text{kW} = 0.323\ \text{hp}$$



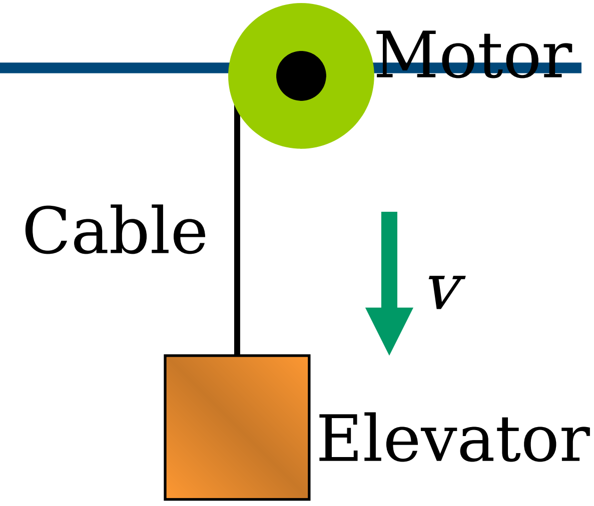


Let's try the calculation again using Eq.(6.17).

$$P_{av} = F_{\parallel} v_{av} = (mg) v_{av} = (50.0\ \text{kg})(9.80\ \text{m/s}^2)(0.492\ \text{m/s}) = 241\ \text{W}$$

Q6.2

An elevator is being *lowered* at a constant speed by a steel cable attached to an electric motor. Which statement is correct?



A. The cable does positive work on the elevator, and the elevator does positive work on the cable.

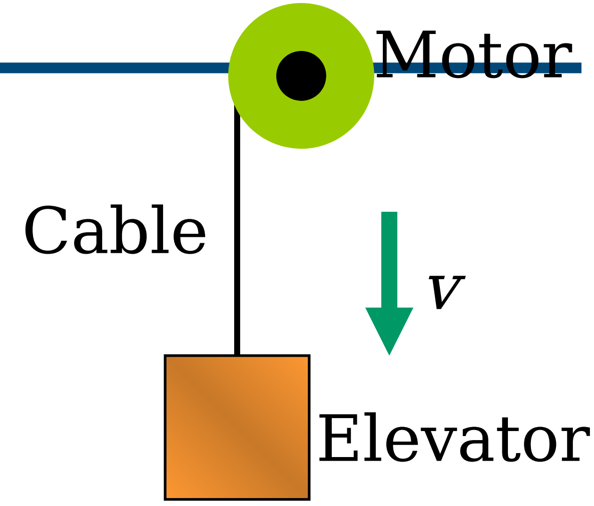
B. The cable does positive work on the elevator, and the elevator does negative work on the cable.

C. The cable does negative work on the elevator, and the elevator does positive work on the cable.

D. The cable does negative work on the elevator, and the elevator does negative work on the cable.

A6.2

An elevator is being *lowered* at a constant speed by a steel cable attached to an electric motor. Which statement is correct?



A. The cable does positive work on the elevator, and the elevator does positive work on the cable.

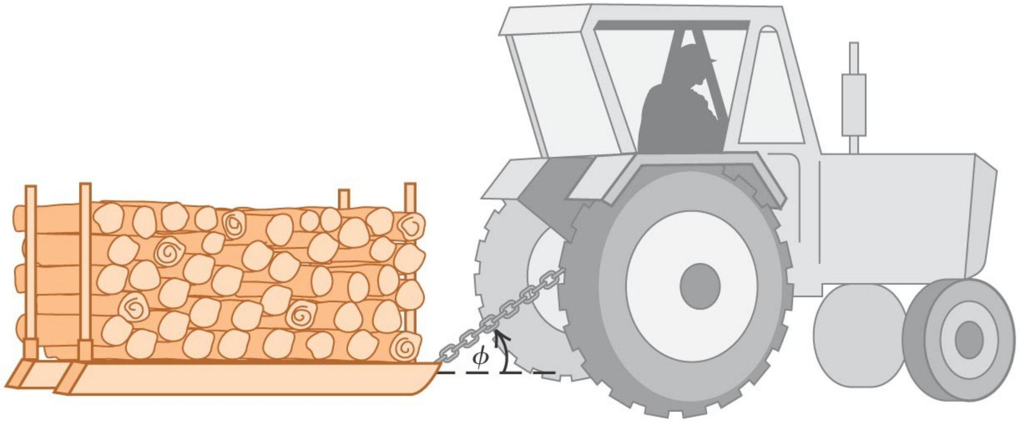
B. The cable does positive work on the elevator, and the elevator does negative work on the cable.

C. The cable does negative work on the elevator, and the elevator does positive work on the cable.

D. The cable does negative work on the elevator, and the elevator does negative work on the cable.

Q6.4

A tractor driving at a constant speed pulls a sled loaded with firewood. There is friction between the sled and the road.



The total work done on the sled after it has moved a distance d is

A. positive.

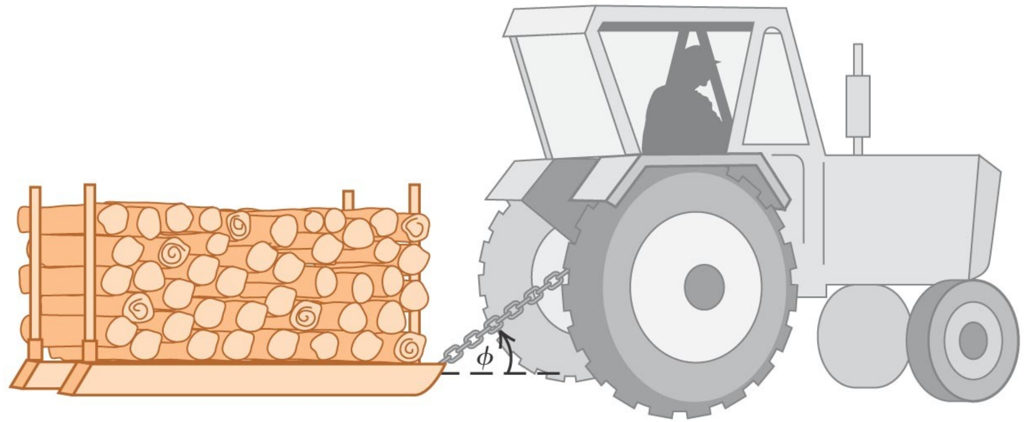
B. negative.

C. zero.

D. not enough information given to decide

A6.4

A tractor driving at a constant speed pulls a sled loaded with firewood. There is friction between the sled and the road.



The total work done on the sled after it has moved a distance d is

A. positive.

B. negative.

C. zero.

D. not enough information given to decide

Q6.5

A nonzero net force acts on an object. Which of the following quantities could be *constant?*

A. the object’s kinetic energy

B. the object’s velocity

C. both of the above

D. none of the above

A6.5

A nonzero net force acts on an object. Which of the following quantities could be *constant?*

A. the object's kinetic energy

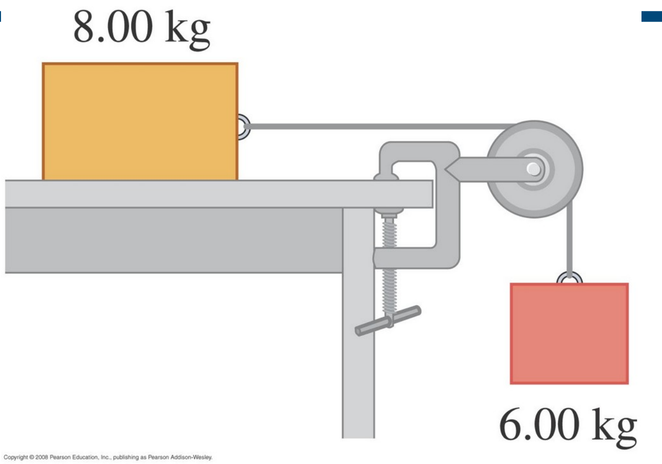
B. the object's velocity

C. both of the above

D. none of the above

Q6.6

A 6.00-kg block and an 8.00-kg block are connected as shown. When released, the 6.00-kg block accelerates downward and the 8.00-kg block accelerates to the right. After each block has moved 2.00 cm, the force of gravity has done



A. more work on the 8.00-kg block than on the 6.00-kg block.

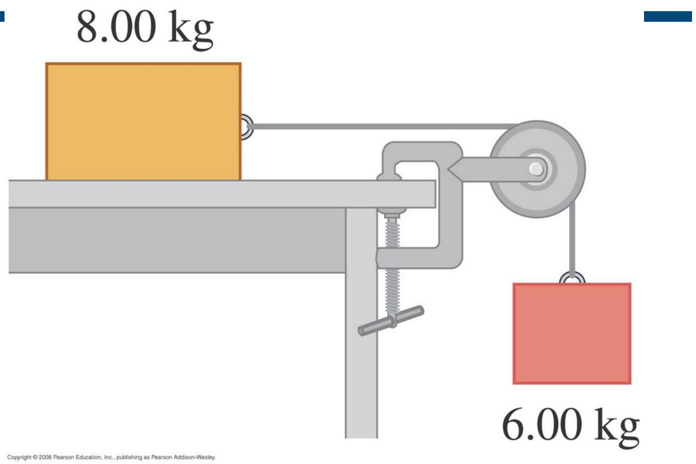
B. the same amount of work on both blocks.

C. less work on the 8.00-kg block than on the 6.00-kg block.

D. not enough information given to decide

A6.6

A 6.00-kg block and an 8.00-kg block are connected as shown. When released, the 6.00-kg block accelerates downward and the 8.00-kg block accelerates to the right. After each block has moved 2.00 cm, the force of gravity has done



A. more work on the 8.00-kg block than on the 6.00-kg block.

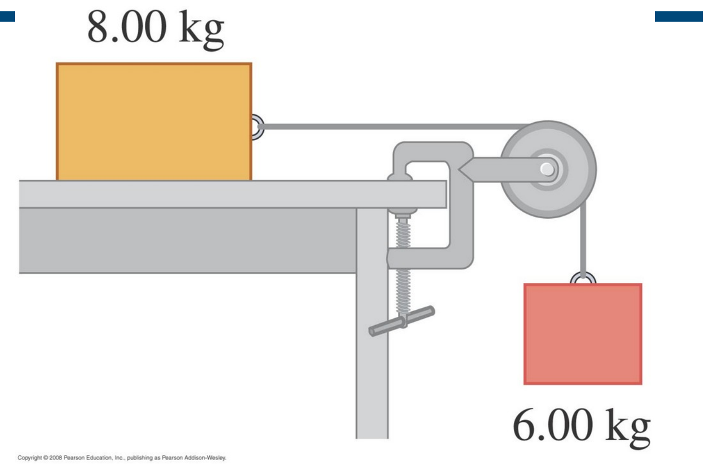
B. the same amount of work on both blocks.

C. less work on the 8.00-kg block than on the 6.00-kg block.

D. not enough information given to decide

Q6.7

A 6.00-kg block and an 8.00-kg block are connected as shown. When released, the 6.00-kg block accelerates downward and the 8.00-kg block accelerates to the right. After each block has moved 2.00 cm, the total work done on the 8.00-kg block



A. is greater than the total work done on the 6.00-kg block.

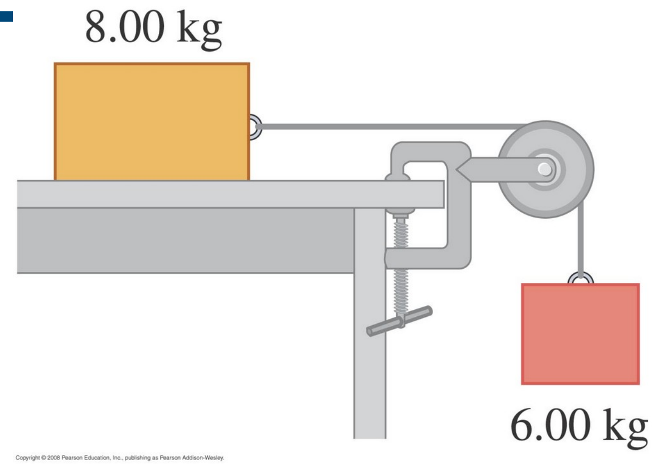
B. is the same as the total work done on the 6.00-kg block.

C. is less than the total work done on the 6.00-kg block.

D. not enough information given to decide

A6.7

A 6.00-kg block and an 8.00-kg block are connected as shown. When released, the 6.00-kg block accelerates downward and the 8.00-kg block accelerates to the right. After each block has moved 2.00 cm, the total work done on the 8.00-kg block



A. is greater than the total work done on the 6.00-kg block.

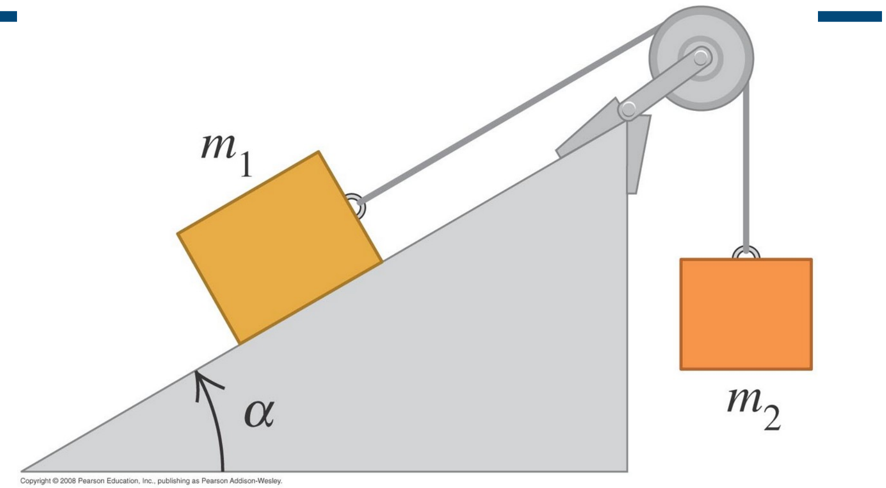
B. is the same as the total work done on the 6.00-kg block.

C. is less than the total work done on the 6.00-kg block.

D. not enough information given to decide

Q6.9

Two blocks are connected as shown. The rope and pulley are of negligible mass. When released, the block of mass m_1 slides down the ramp and the block of mass m_2 moves upward.



After each block has moved a distance d, the total work done on m_1

A. is greater than the total work done on m_2.

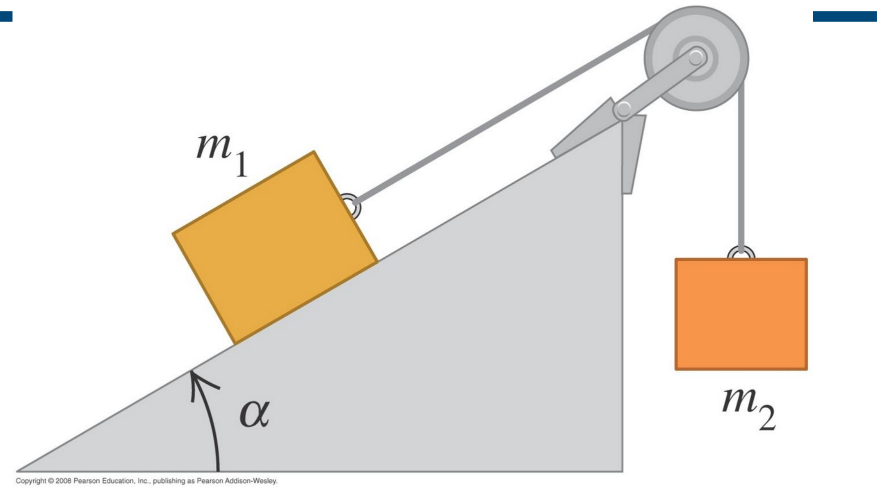
B. is the same as the total work done on m_2.

C. is less than the total work done on m_2.

D. not enough information given to decide

A6.9

Two blocks are connected as shown. The rope and pulley are of negligible mass. When released, the block of mass m_1 slides down the ramp and the block of mass m_2 moves upward.



After each block has moved a distance d, the total work done on m_1

A. is greater than the total work done on m_2.

B. is the same as the total work done on m_2.

C. is less than the total work done on m_2.

D. not enough information given to decide

Q6.10

An object is initially at rest. A net force (which always points in the same direction) is applied to the object so that the *power* of the net force is constant. As the object gains speed,

A. the magnitude of the net force remains constant.

B. the magnitude of the net force increases.

C. the magnitude of the net force decreases.

D. not enough information given to decide

A6.10

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A. the magnitude of the net force remains constant.

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C. the magnitude of the net force decreases.

D. not enough information given to decide

Homework:

6.14, 6.41, 6.46